GUTTING & FOLEY

Ozone Purification of Water

Electrical Engineering

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OZONE PURIFICATION OF WATER

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Leo Arthur Gutting and John Warner Foley

ENTITLED Ozone Purification of Water.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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GENERAL OUTLINE.

OZONE PURIFICATION OF WATER.

I

Introduction.

Ozone is a most effective water sterilizer because of its powerful destructive action upon all organic matter. This fact has been verified by experiments conducted over a long period of time. As yet little has been accomplished in ozone water purification by Americans, the Lindsey plant* having proved to be unsuccessful. The failure of this installation, according to the report of the investigating board, was due entirely to mechanical defects in the method of treatment.

In Europe, ozone has been used successfully for some time as a sterilizing agent in many different water purifying plants, and equipments located at Schierstein and Paderborn** have given complete satisfaction. The apparatus in each of the above installations was built by the Siemens and Halske Company of Berlin. The Schierstein plant is designed to sterilize 66000 gallons of water per hour, but only about one-half of this amount is ordinarily used. This plant is divided into two independent units, one being in operation while the other is at rest. Electric generators provide power for operating the pumps and supplying the step-up transformers which deliver energy to the ozonizers at 6500 volts. After passing thru the ozonizers the air is driven up thru

* Canadian Engineer. Vol. 18. Number 28. Also June 3, 1910.
**Experimental Electro-chemistry. N. Monroe Hopkins, Ph.D.

the sterilizing towers by means of fans, where it mixes thoroughly with the water.

The sterilizing towers are built of brick and divided into four sections by perpendicular walls. Each of these four sections is filled with coarse gravel, thru which the water trickles and presents a large surface to the ozonized air. Thru the combined sections of each tower water passes at the rate of 16,100 gallons per hour and ozonized air is driven upward at the rate of 2,800 cubic feet per hour. 1.905 cubic feet of air being used to sterilize 1 cubic foot of water. The cost of this purification is given as .35 cents per cubic meter (.01 cents per cubic foot).

Tests of the sterilized water by German chemists and bacteriologists has proved that the treatment of water with the above described apparatus is in every way successful so far as the destruction of germs and bacteria is concerned.

So far as could be ascertained, ozone water purifiers have been confined entirely to plant installation such as the Schierstein system. Obviously a small ozonizer for household use would be very desirable in locations where a large plant could not be installed to advantage. Such an ozonizer would necessarily need to be compact and inexpensive, and, to fulfill both of these requirements, treatment could not be effected by forcing the ozonized air thru the water by the methods used in plant purifying apparatus because of the large outlay for accessories and excessive space which would be necessary. The idea upon which this investigation has been based is to employ an aspirator for drawing in the ozonized air and mixing it with the water. This would form a

simple and inexpensive means of bringing the water and ozonized air together, and would require little space. The real problem is, then, to determine conditions by which a sufficient concentration of ozone can be produced to sterilize the water, and to find the feasibility of this method of purification.

ELECTRICAL PRODUCTION OF OZONE.

II

Ozone is a peculiar form of oxygen, the exact composition of which is doubtful, as it has never been obtained in a pure state, being always accompanied by oxygen. However, there are good reasons for believing that it is composed of three atoms of oxygen. Ozone may be produced by several different chemical reactions such as the slow oxidation of phosphorus or sulphur, and also by several electrolytic actions. The most effective method of production, however, is by means of a silent electrical discharge thru oxygen or air.* This phenomenon was first discovered by Van Marum in 1785, when he noticed that oxygen, upon being exposed to electrical discharges, acquired an odor similar to that experienced after the atmosphere had been subjected to an active electrical storm. Subsequent experiments have proved that this odor was due to the presence of a powerful oxidizing form of oxygen, since known as ozone. Numerous forms of apparatus have been designed to produce ozone electrically for commercial use.

If the conductor of a Holtz electrical machine be connected to a point, there will be an outflow of electricity from the latter. In a dark room a small ball of light can be seen around the point, which will assume the form of a brush if there is a sufficient flow of electricity. The discharge is discontinuous, as can easily be proved by use of a rotating mirror. When the discharge takes place

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* Experimental Electro-chemistry. N. Monroe Hopkins, Ph.D.

in the air, the peculiar odor characteristic of ozone becomes perceptible.

When a dielectric circuit, composed of two electrodes separated by some insulator, such as glass or mica, is subjected to a constantly increasing, alternating e. m. f., a certain value of the latter is reached at which a pale violet light, called corona, will form and extend into the air. This corona has considerable heating effect, and renders the air near the electrodes more conducting. As the e. m. f. continues to increase, little flashes of light, called streamers, dart thru the corona and extend towards the edge of the electrodes. These streamers have a marked heating capacity. A gas enclosed between the two electrodes is soon brought to the glowing point, and in the case of air a comparatively large amount of ozone is formed from the contained oxygen.

All the conditions of the above phenomena agree in this respect, - that, for an exceedingly short time, the enclosed gas is heated to the glowing point, and then cools. Judging from the spectra of the gases glowing under the influence of the action of points, sparks, or electrical oscillations, the temperature at certain times is much higher than that of the arc light. This is deduced from the fact that spark spectrum excels the arc spectrum in number of lines and brilliancy just as the latter excels that obtained with a Bunsen burner. Of course quantitative differences exist between the phenomena of the action of points, spark discharges, and vibrations in the ether, in so far as the

best effect is concerned, according to the greater or smaller quantity of energy possessed by the discharge; but all must, as the spectra prove, produce a higher temperature than the arc light for a very short time.

At these high temperatures, chemical reactions proceed in quite a different direction from that taken at the ordinary temperatures, and the velocities are also much greater. During the extremely short time of heating, the gas pressure cannot come into equilibrium with that of the surrounding atmosphere, and it is assumed that the pressure of the gas stands in about the same ratio to that of the atmosphere as do the corresponding absolute temperatures, i.e. 20:1. After the short heating, a sudden cooling takes place, so that the products of the reaction are prevented from passing back to the original condition during the cooling interval.

The chemical equation for the formation of ozone is:

$$3\ O_2 \rightleftarrows 2\ O_3$$

This reaction is reversible, that is, it proceeds in both directions at the same time. The speed of the reaction in each direction depends on the temperature and concentrations of the two substances. For any given temperature the concentration of the two will change until the speed at which either is decomposed just equals the rate at which it is formed. At very high temperatures, the speed of the reaction to the right is greatly accelerated in proportion to the speed in the opposite direction. Hence, the quantity of ozone present is greatly increased. For

medium temperatures just the opposite condition prevails, thus decreasing the proportion of ozone. The reaction does not take place at low temperatures.

The action of the electrical discharge in forming ozone is as follows: At the instant of the discharge the oxygen is heated to a very high temperature, at which the point of chemical equilibrium is displaced to the right. As a result, a considerable quantity of ozone is formed. Almost instantly the gas is cooled to a comparatively low temperature, at which the reaction decomposing the ozone does not take place. Hence, the concentration of the latter remains fairly high.

The formation of ozone is effected by a number of conditions. (1) Low temperatures increase the yield, since the amount formed is not so readily decomposed. (2) The presence of dust decreases the quantity since ozone is lost in oxidizing it. (3) The amount also diminishes with decreasing atmospheric pressure. (4) Chlorine or oxidation products of nitrogen, if present, hinder its formation. (5) The yield is promoted by hydrogen, if the formation of water is rigidly avoided.

Working at atmospheric pressure Hautefeuille and Chaprius obtained the following percentages of ozone by weight:-*

Temp. ° C.	-23	0	20	100
Percent O_3 by weight	21.4	14.9	10.	---

These correspond to the following percentages by volume respectively:

14.32	9.97	7.02	---

* Text Book of Electro-chemistry, by Svante Arrhenius.

Numerous ozonizers have been designed and built, ranging in size from small laboratory apparatus to large affairs for commercial use. Of these, the ozonizers constructed by Siemens and Halske Company, and by Andreoli, have given the best results.*

"The Siemens and Halske ozonizer consists of two concentric tubes, coated inside and outside and separated by a thin mica plate placed close to the inside of the outer tube, and by a narrow space thru which the air to be ozonized must pass. It works with an alternating current of 6500 volts; the yield, i.e., the quantity of heat consumed in the ozone formation (36000 cal. for 48 grams), corresponds with only 3.2 percent of the electrical energy spent.* The inner tube is kept cold by a stream of water".

Andreoli claims that his ozonizer gives a yield of ozone about five times as great as that obtained by Siemens and Halske for the same energy consumption, namely, as high as 120 grams of ozone per kilowatt-hour.* His apparatus consists essentially of a number of square aluminum plates about 70 cm. on a side. Every second one is smooth, while the others are in the form of grids, composed of 80 pieces of notched aluminum strips, each of which possesses 111 points. The smooth and grid plates are separated by thin panes. Five pairs of these insulated plates are combined in one system. A unit composed of eight such systems, when actuated by an induction coil, whose primary current was 5.9 amperes at 85 volts and secondary at 3000 volts, absorbed 500 watts and gave 60 grams of ozone per hour. The air is blown thru the various systems and, on account of the small amount of energy consumed, no further

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* Text Book of Electro-chemistry, by, Svante Arrhenius

cooling device is necessary. As in the Siemens and Halske ozonizer, the volume of air treated for a given amount of ozone is very large, thus giving a very small concentration.

METHOD AND MANIPULATION.

III

The experimental work for this investigation naturally divided itself into three parts: (1) The production of the ozone; (2) Method of sterilizing the water; and, (3) The effect upon the impurities.

Since the design of any ozonizer depends largely upon the quantity of air to be treated in a given time and the concentration of ozone desired, the first condition to be determined was the ratio of the volume of air to that of the water. This proportion was evidently controlled by the method of mixing the two. In this problem, since it was the intention to use an aspirator for this purpose, the ratio was fixed by the capacity of the latter.

An efficient aspirator, of which a sectional view is shown in Fig. 1, was obtained from C. H. Stoelting Company of Chicago. The aspirator connected with the main at A, and the water in passing thru the nozzle B was transformed into a jet. This jet, after passing thru the narrow neck D, was broken into fine particles upon striking the side of staggered tube E. These mingled thoroughly with the air in the tube and carried it out at the lower end, thus creating a partial vacuum at the upper end of E. This vacuum in conjunction with the action of the jet in passing thru the neck D, drew air in thru the passage C.

A test by direct measurements, to determine the ralative volumes of air and water passing thru the aspirator, showed that the ratio of the air to the water was 1 : 2 when a pressure of

40 pounds per sq. in. was used. This ratio could be varied between zero and one-half by adjusting the water pressure.

The calibration of the aspirator, showing that it could draw in only one volume of air to purify two volumes of water, indicated at once that air containing a very high concentration of ozone would be required for effective sterilization, inasmuch as the amount of ozonized air used by the Siemens and Halske purifier was nearly four times this amount for a given volume of water. In addition to this, the period of contact was much longer in the Siemens and Halske apparatus than could be obtained with any aspirator.

The first attempt to construct an ozonizer consisted of wrapping No. 14 copper wire, one-half inch apart, about two boards, to form the electrodes. This proved unsatisfactory for two reasons, viz., a very high voltage was necessary to produce corona, and it was very difficult to adjust the distance between the wires so as to obtain a uniform discharge from all of the turns.

To remedy these defects, two electrodes were designed and constructed from brass plates. One plate was left smooth, but upon one face of the other a series of parallel V-shaped ridges were cut. The electrodes were square, being 4 in. on an edge. A hole was drilled thru the center of the upper plate and fitted with a tube which was connected to the aspirator. The distance between the plates was adjusted by squares of fiber insulation placed as shown in Figure II. With this arrangement, the air entered the ozonizer on approximately the circumference of a circle of two inch radius and left thru a small opening at the center. Conse-

quently, its velocity increased as it passed between the electrodes towards the outlet.

With just an air space between the electrodes only ordinary arcs were obtained, but when some other dielectric, such as a sheet of glass or mica, was used in addition to the air space, the violet glow indicative of corona was formed. At the same time a strong odor similar to that of ozone became perceptible. Qualitative tests, consisting of exposing starch potassium iodide papers or pink litmus papers moistened in potassium iodide - both of which turn blue in the presence of ozone - to the gases issuing from the ozonizer, proved that ozone was being formed.

As it was necessary to know the exact amount of ozone formed some method of quantitative measurement was required. The best results obtained by previous experiments, using pure oxygen, has been from five to seven percent converted into ozone. Since air is approximately one-fifth oxygen, only about one percent of the air could be changed into ozone, provided the same ratio of transformation could be obtained from the oxygen cortained in the air. Such a small percent practically prohibited the direct measurement of the ozone by absorbents, and the method chosen consisted of allowing it to react with some substance of which the chemical equation expressing the reaction with ozone was known. From this equation the amount of ozone could easily be determined.

The reagent chosen for this purpose was a solution of potassium iodide (K I), which reacts with ozone to give free iodine, potassium hydroxide (KOH), and free oxygen (O_2). The amount of

iodine set free could easily be measured by titrating against a standard solution of sodium thio-sulphate ($Na_2S_2O_3$). The equation for the reaction of ozone (O_3), and a potassium iodide solution is:

$$2\ KI + O_3 + H_2O \rightleftharpoons I_2 + 2\ KOH + O_2.$$

and for iodine (I_2) with sodium thio-sulphate:

$$I_2 + 2\ Na_2S_2O_3 \rightleftharpoons Na_2S_4O_6 + 2\ Na\ I.$$

The chief objection to this method is that the presence of nitrous oxide or hydrogen peroxide will also liberate iodine.

A $\frac{I}{10}$ normal solution of $Na_2S_2O_3$ was made and standardized by titrating against a standard solution of iodine. From this a $\frac{I}{100}$ normal solution was obtained as required by adding 100 cc. of $\frac{N}{10}$ $Na_2S_2O_3$ to .9 liter of distilled water. From the above equations it is seen that 22.4 liters of ozone equals 254 grams of iodine; which is equivalent to 2 molecular weights of $Na_2S_2O_3$. Therefore, it would require $\frac{I}{100}$ molecular weight per liter for $\frac{N}{100}$ $Na_2S_2O_3$, and 1 cc. of $\frac{N}{100}$ $Na_2S_2O_3$ would represent.000112 liters of ozone.

The apparatus employed in making the tests for the determination of the quantity of ozone consisted of a 110 to 11000 volt transformer, the ozonizer, two gas washing bottles, a gas meter, voltmeter, rheostat, and the aspirator. The arrangement as used for each test is shown in Fig. III. All connections between the ozonizer and the wash bottles were made of glass with sealed joints, so that no ozone could come in contact with rubber tubing, or metal after leaving the ozonizer.

The air, which was drawn thru by the aspirator, was subjected to the electrical discharge upon entering the ozonizer. After

passing between the electrodes, the ozonized air bubbled thru the potassium iodide solution in the bottles, its volume being measured by the gas meter. The solution in the first bottle was highly colored by the free iodine liberated while that in the second bottle acquired only a slight tinge. This showed that nearly all of the oxidizing agents were being absorbed in the first bottle, and that none werebeing carried past the second bottle. The quantity of the oxidizing substances present was then determined by titrating against a standard solution of sodium thio-sulphate. This oxidizing mixture consisted almost entirely of ozone, as tests with litmus papers showed that the solution remained neutral. If any of the oxidation products of nitrogen had been present, it would have become acid.

Several tests showed that the amount of ozone varied with the voltage impressed, the velocity of the air between the electrodes and the distance between the latter. In order to determine the best conditions, a series of tests were made with a constant distance between the plates, and a constant rate of flow of air. The voltage was varied by suitable steps between the lowest and highest value possible, - the upper limit being the value where arcs formed.

From this data curve No. 1 was plotted between the percent of ozone formed and the voltage impressed, and the value, which gave the maximum yield of ozone determined from it. With this value of e.m.f. impressed, another series of tests were made, the speed being varied between the working limits of the aspirator, and curve No. 2 plotted between the percent yield and the flow of air

per minute. Then the distance between the plates was changed and the process repeated for curves Nos. 3 and 4.

The voltage curves Nos. 1 and 3 for the brass electrodes showed that the yield of ozone increased to a certain value and then decreased. The speed curves Nos. 2 and 4 likewise indicated that the amount of ozone formed increased as the velocity decreased until a certain point was reached, after which the yield started to decrease with the speed. An examination of the electrodes showed that the upper one, which was exposed to the ozone, was turning green and rapidly corroding. From this it was evident that considerable ozone was being lost thru oxidation of the plate. To avoid this an aluminum plate was substituted for the upper electrode. A similar set of tests was then run under the same conditions as before, and the results plotted.

These curves, Nos. 5, 6, 7, and 8, showed several marked differences from those obtained with the brass electrode. The maximum results for the voltage curves, Nos. 5 and 7, were twenty to forty percent higher, while the yield for the speed curves, Nos. 6 and 8, continued to increase as the rate of flow decreased. The maximum percent by volume of air converted into ozone was 0.813. This was obtained with a voltage of 4850, air flow of .45 liters per minute, and an air space of .15 cm., as shown by curve No. 8.

To determine the effect of the ozone upon impure water passing thru the aspirator, the apparatus shown in Fig. III was modified to the arrangement illustrated by Fig. IV. The ozonizer was connected directly to the aspirator with glass tubing. A reservoir, consisting of a sixteen gallon keg, was placed between the aspirator and the water main. Two valves in the pipes furnished

a means of regulating the flow, while a tap provided a means of obtaining specimens of the water just before it entered the aspirator. The water in the keg was contaminated by introducing a quantity of bacteria and water organisms obtained from the University bacteriological department. Since the reservoir was of a comparatively large size, its contents did not become diluted to any appreciable extent in the short interval during which samples were being taken.

Two different experiments were made upon the impure water. The bacteria for the first test were still suspended in their culture broth, which thereby introduced a large quantity of organic matter into the water. For the second test a watery suspension was used. Samples were taken simultaneously of the entering and leaving water, with the rate of flow varying between the limits of the aspirator. The voltage impressed upon the ozonizer and the air space were the same as those for which the maximum concentration of ozone was obtained. The specimens were analysed by the bacteriological department, and the results were as given on page 40 of the appendix.

The air and water after passing thru the aspirator possessed a strong odor of ozone, which disappeared if water was allowed to stand for a short interval. Tests with starch potassium iodide papers showed that the ozone was not being entirely absorbed. A disagreeable odor, which the water possessed before treatment, was not noticeable afterwards.

DISCUSSION

IV

The accuracy of the data secured for the various curves was affected by several factors. The gas meter used for measuring the volume was only reliable to within three percent. Neither could the voltage be determined accurately since it was measured on the low potential side of the transformer. When ozone was being formed, considerable energy was consumed. This would cause a drop in the transformer and, hence, the e.m.f. impressed upon the ozonizer would not be the primary voltage multiplied by the ratio of turns. Another circumstance which caused considerable trouble was the variation of the water pressure. This made it practically impossible to keep the speed constant within a closer degree than five or seven percent. The voltage curves were especially affected by this condition.

The ozonizer proved very erratic in its behavior, with both the aluminum and brass electrodes. With the latter, it gave excellent results for the first few tests, after which the yield apparently decreased for the same conditions. No satisfactory result could be obtained until the apparatus had been allowed to rest for some time. The only explanation suggested for this was that the oxidized brass, when allowed to stand, formed a coating over the surface of the electrode, which hindered the union of the ozone and metal at first, but, being soon peretrated, allowed a rapid reaction to take place after a short interval.

The aluminum electrode was not affected in this manner, since a thin continuous layer of oxide soon formed on the surface and prevented further reaction. It was, however, very sensitive to changes in the atmospheric conditions. A slight rise in the temperature would greatly decrease the yield of ozone. In several instances, when the electrodes became heated, the amount formed was decreased fifty percent.

The number of bacteria destroyed in bacteriological test No. I was reduced to some extent by the presence of other organic matter, since a large proportion of the ozone was lost in oxidizing this. The result obtained from sample No. I was probably erroneous, since none of the others taken under similar conditions showed an equal percent reduction.

In the second test, where there was no organic matter present, the highest percent reduction of bacteria was 58 percent. This was for a very slow flow. For a flow twice as great, the percent killed was only 33.3 percent or approximately one-half as many. This indicates that a longer period of contact is needed rather than a higher concentration of ozone, since all of the latter was not absorbed. The only way to secure a longer contact would be to lengthen the aspirator tube. The increase of back pressure caused by this would decrease the efficiency of the aspirator, thus curtailing the supply of ozone. Hence, little could be accomplished by this means.

CONCLUSIONS.

V

Although this investigation was not carried far enough to prove beyond a reasonable doubt whether or not this method of purifying water is feasible, several definite conclusions can be drawn from the results obtained. First, an ozonizer giving an exceedingly high concentration of ozone would be necessary if used in connection with an aspirator. Such an ozonizer would work satisfactorily only under the best state of external circumstances, as any sudden change of atmospheric conditions, such as a rise of temperature or increase of water vapor, would decrease the amount of ozone formed and consequently the affectiveness of the water sterilization. For this reason the apparatus could not be depended upon to give pure water at all times unless some means were provided for keeping the conditions constant. This would necessitate some form of chemical drying apparatus and an effective arrangement for cooling the electrodes. These accessaries would greatly increase the cost and attention required.

Briefly summed up, the main points against this method of purifying water are: (1) Expense of construction with proper accessaries; (2) Amount of attention required; (3) A large proportion of the bacteria would not be distroyed, and, (4) A strong odor of ozone remains in the water making it unfit for immediate use. The fact that the disagreeable odor was eradicated from the water is not an argument in favor of the apparatus, since it removes all

indications of the presence of impurities without destroying the latter. With these conditions existing,it is difficult to conceive how this method of sterilizing water would be of any practical use.

VI

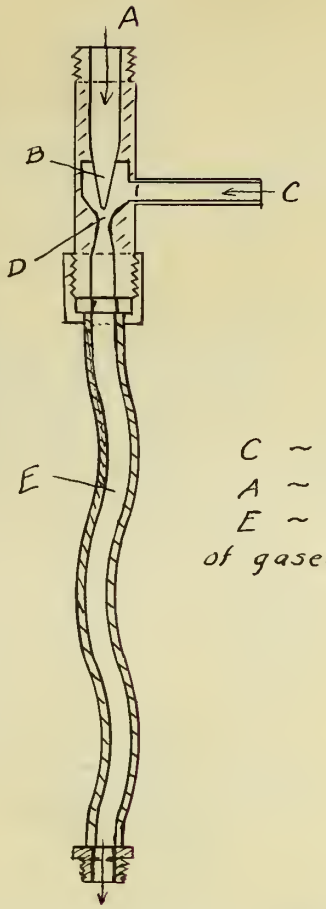
A P P E N D I X:

(a) Drawings of the apparatus.

(b) Logs of data.

(c) Curves.

FIGURE NO. I.



C ~ Entering gases.
A ~ Entering water.
E ~ Leaving mixture of gases and water.

DIAGRAM OF ASPIRATOR.

FIGURE NO. II.

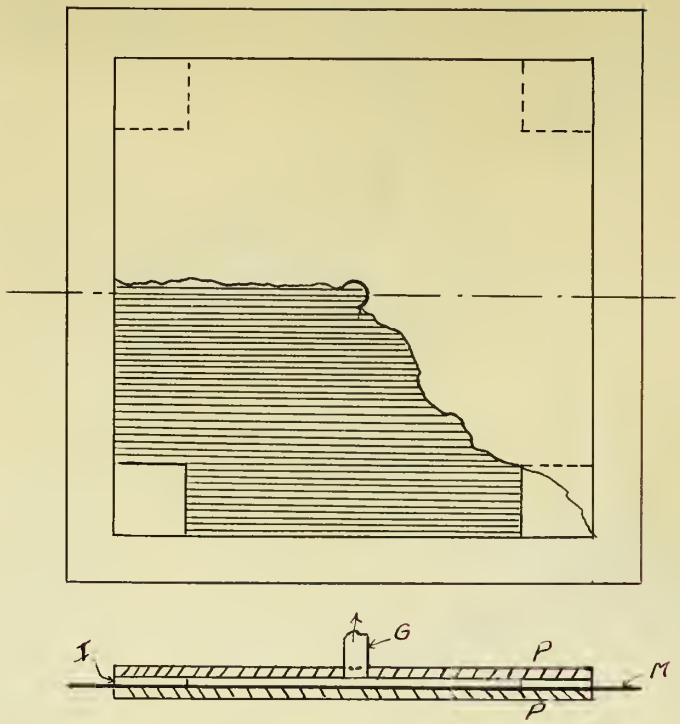
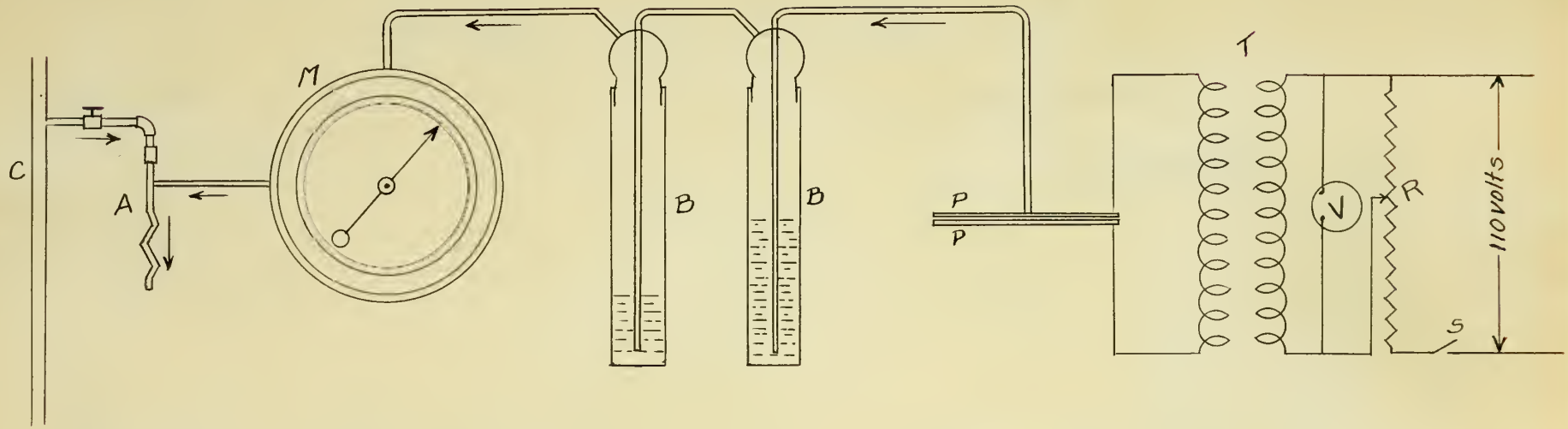


DIAGRAM OF PLATES.

I ~ Fibre space pieces.
G ~ Glass tube.
P.P ~ Plates.
M ~ Mica dielectric.

FIGURE NO. III.

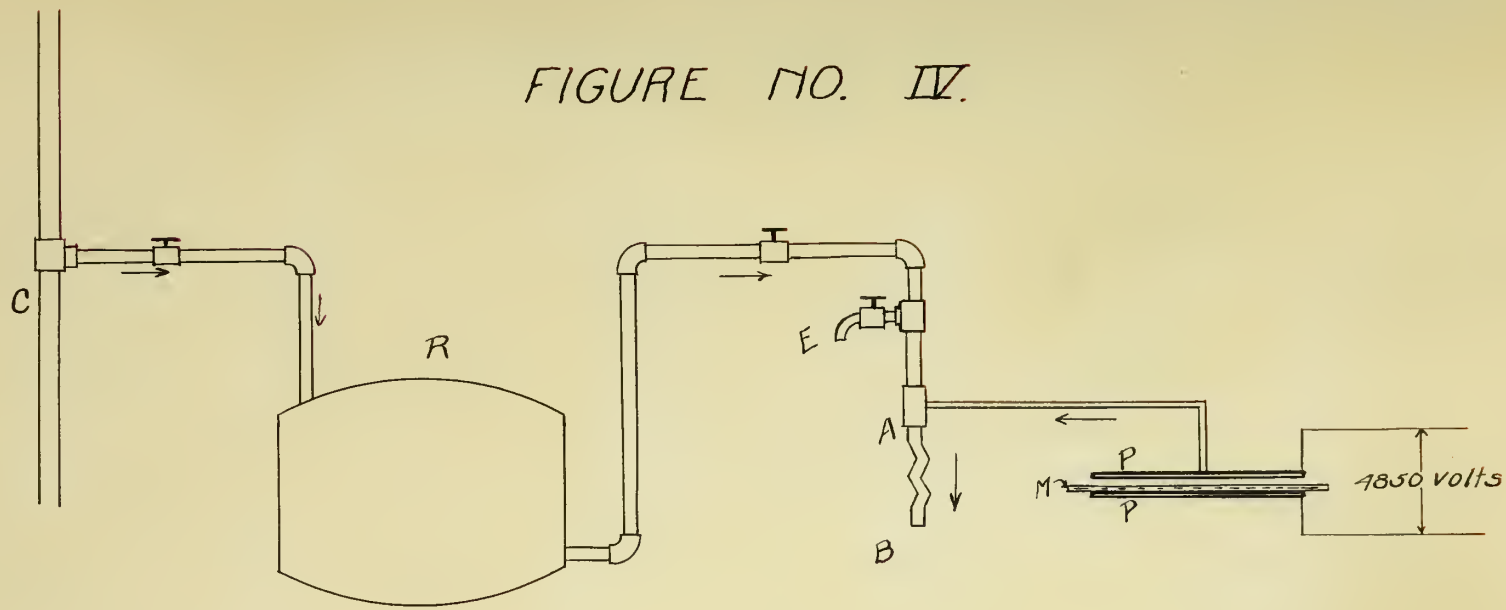


C ~ Water main.
A ~ Aspirator.
M ~ Gas meter.
B-B ~ Wash bottles.
P-P ~ Plates.
T ~ 1-100 Transformer.
R ~ Rheostat.
S ~ Switch.
V ~ 0-60-120 Voltmeter.

DIAGRAM OF APPARATUS.

As used for determination of the amount of ozone obtained under different conditions.

FIGURE NO. IV.



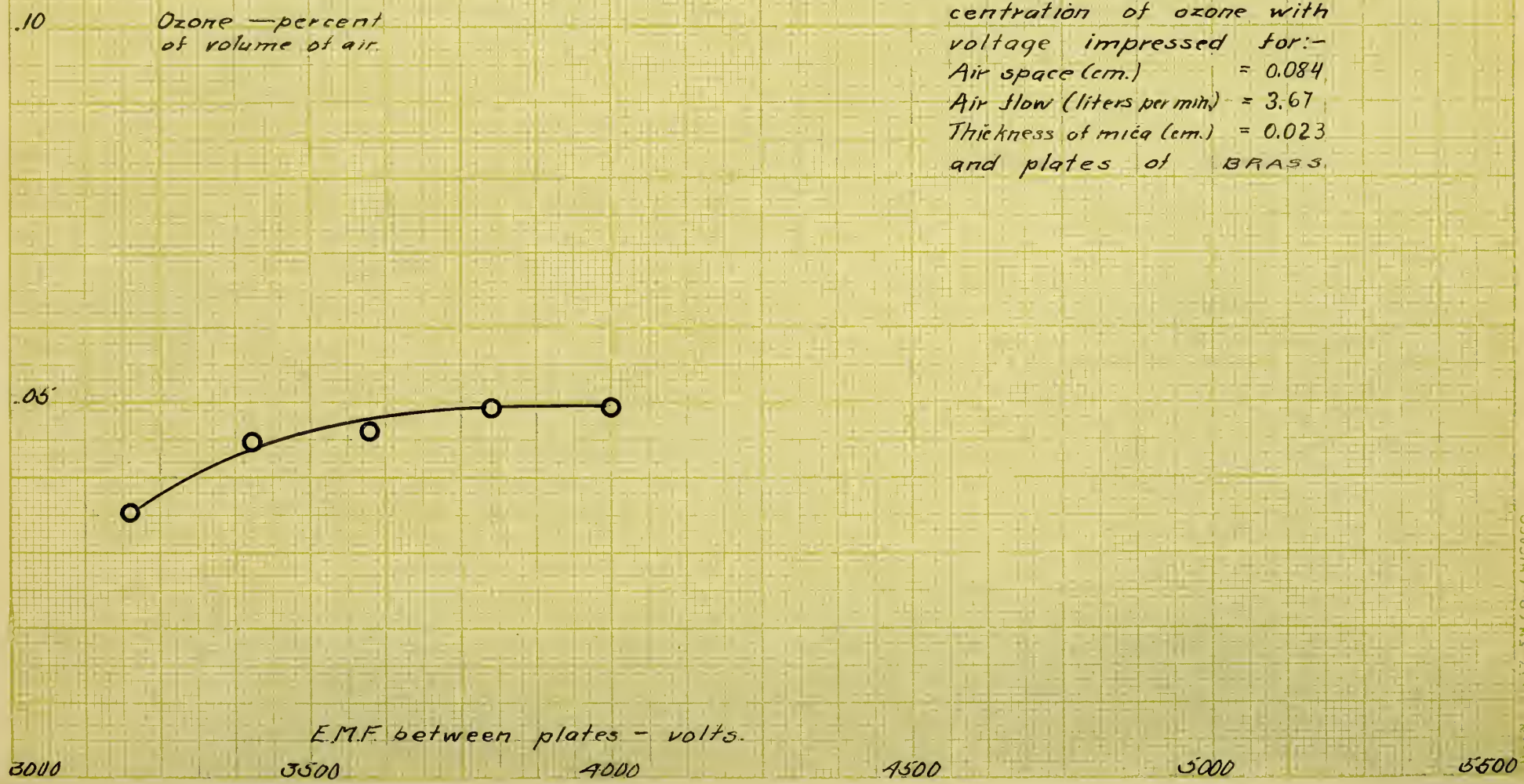
C ~ Water main.
R ~ Reservoir containing bacteria.
E ~ Tap for entering samples.
L ~ Leaving samples.
A ~ Aspirator.
P.P ~ Aluminium plates.
M ~ Mica insulation.

DIAGRAM OF APPARATUS.

As used for determination of the effect of ozone upon contaminated water.

TEST NO. I.
VOLTAGE CURVE NO. I.

Showing variation of concentration of ozone with voltage impressed for:-
Air space (cm.) = 0.084
Air flow (liters per min.) = 3.67
Thickness of mica (cm.) = 0.023
and plates of BRASS.



DATA FOR VOLTAGE CURVES.

Test No. I

Plate used - Brass. Thickness of mica - .023 cm.

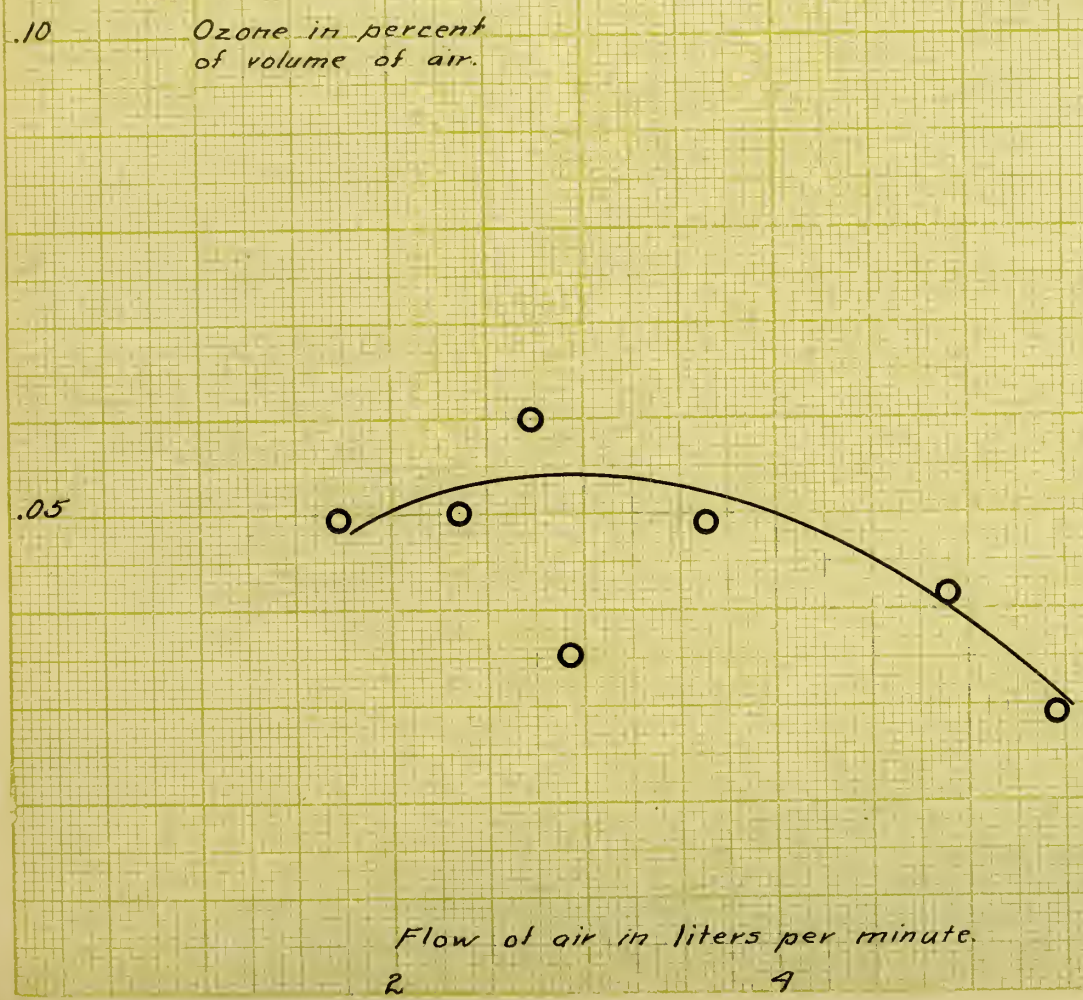
Volts impressed - 3200 - 4000. Air space between mica and plate - .084 cm.

Liters of air treated	Voltage between plates	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	3200	66.00	3.64	12.65	3.16	0.0354
4.0	3400	70.00	3.43	16.05	4.01	0.0449
4.0	3600	64.00	3.75	16.50	4.12	0.0460
4.0	3800	66.00	3.64	17.55	4.39	0.0492
4.0	4000	64.00	3.75	17.60	4.40	0.0493

TEST NO. I.
SPEED CURVE NO. 2.

Showing variation of concentration of ozone with flow of air for:—

Air space (cm.) = 0.084
E.M.F. impressed (volts) = 3800
Thickness of mica (cm.) = 0.023
and plates of BRASS.



DATA FOR SPEED CURVES.

Test No. I

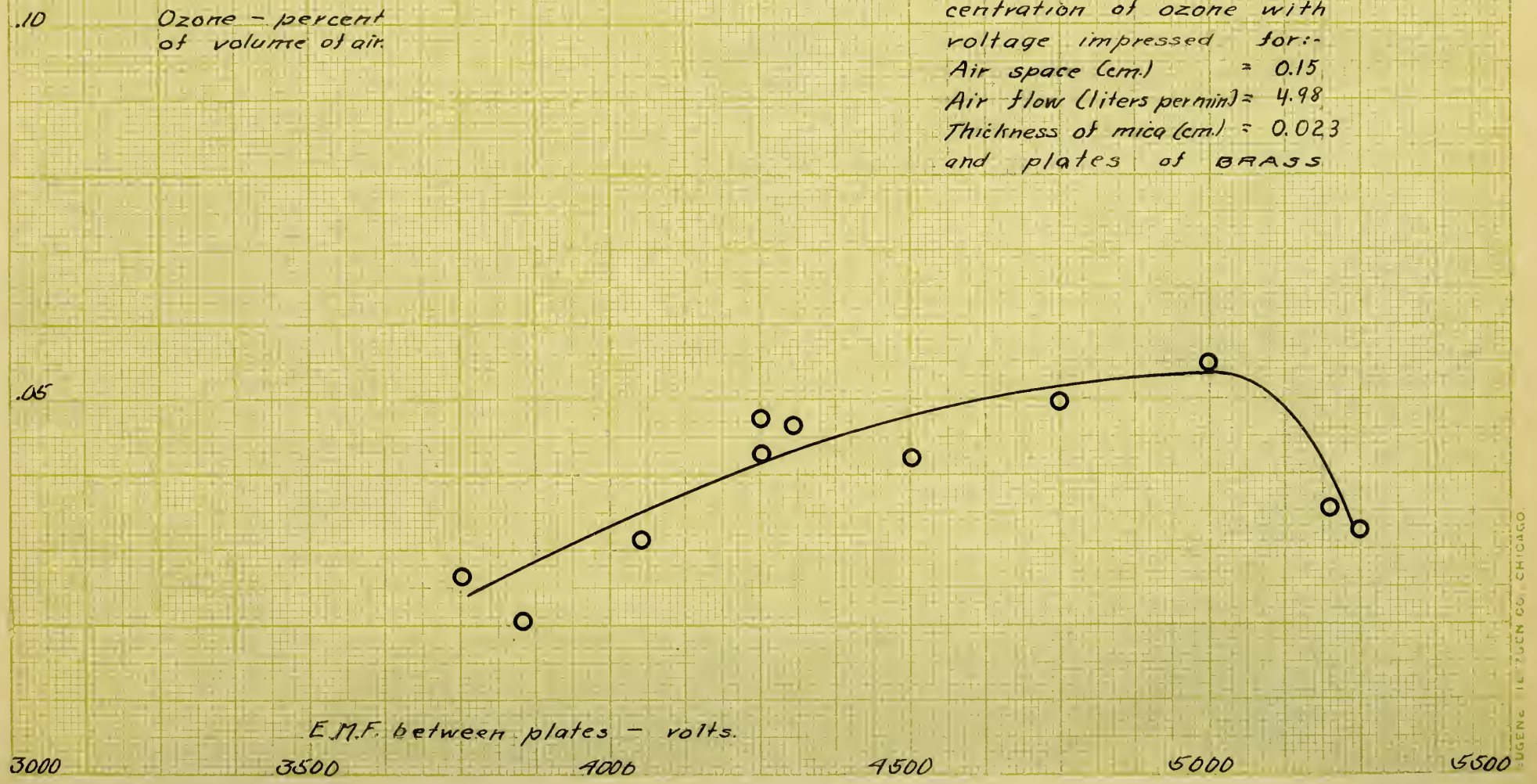
Plate used - Brass. Thickness of mica - .023 cm.

Volts impressed - 3800. Air space between mica and plate - .084 cm.

Liters of air treated.	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	140	1.72	17.75	4.44	0.0496
4.0	102	2.36	17.90	4.47	0.0501
4.0	88	2.73	21.45	5.36	0.0600
4.0	82	2.93	12.70	3.17	0.0355
4.0	66	3.64	17.55	4.39	0.0491
4.0	49	4.90	14.85	3.71	0.0415
4.0	44	5.46	10.40	2.60	0.0291

TEST NO. II.
VOLTAGE CURVE NO. 3.

Showing variation of concentration of ozone with voltage impressed for:-
Air space (cm.) = 0.15
Air flow (liters per min) = 4.98
Thickness of mica (cm.) = 0.023
and plates of BRASS



DATA FOR VOLTAGE CURVES.

Test No. II

Plate used - Brass. Thickness of mica - .023 cm.

Volts impressed - 3750 - 5250. Air space between mica and plate - .15 cm.

Liters of air treated.	Voltage between plates.	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	3750	50.00	4.80	9.50	2.37	0.0265
4.0	3850	60.00	4.00	7.35	1.84	0.0206
4.0	4050	65.00	3.70	11.20	2.80	0.0314
4.0	4250	46.00	5.21	16.95	4.24	0.0475
4.0	4250	54.00	4.55	15.35	3.84	0.0430
4.0	4300	53.00	4.53	16.65	4.16	0.0466
4.0	4500	48.00	5.00	15.05	3.76	0.0421
4.0	4750	49.00	4.90	17.75	4.44	0.0497
4.0	5000	49.00	4.90	19.65	4.91	0.0550
4.0	5200	47.50	5.05	12.70	3.17	0.0355
4.0	5250	49.00	4.90	11.65	2.91	0.0326

TEST NO. II.

SPEED CURVE NO. 4.

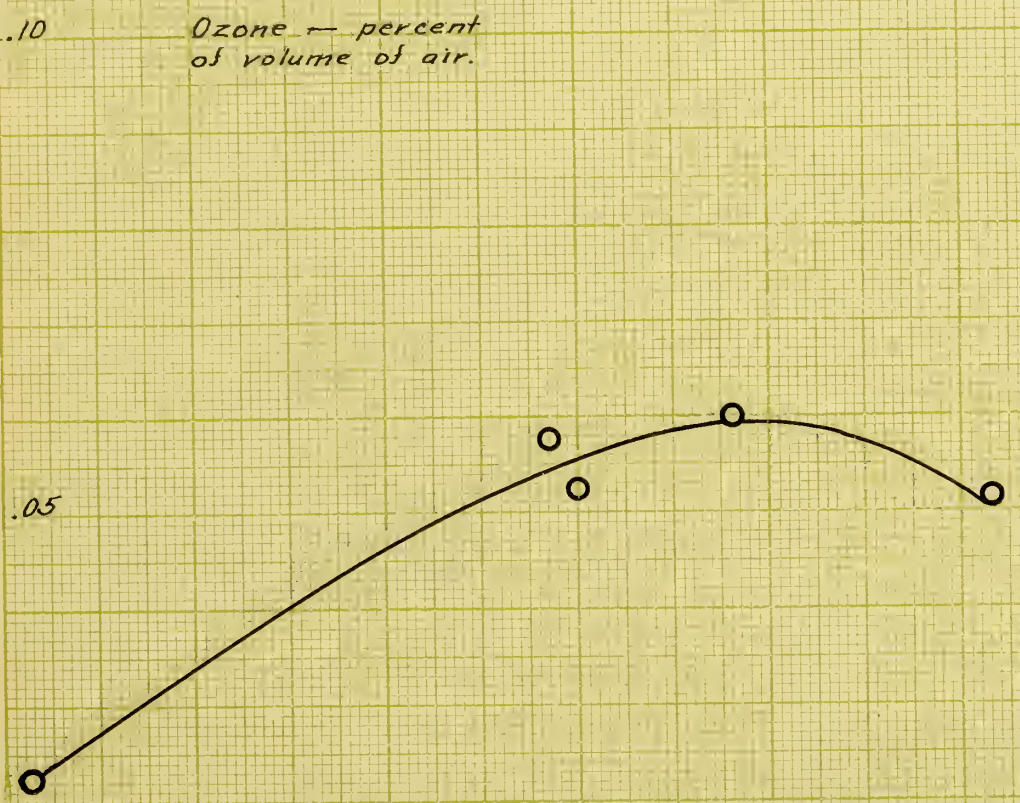
Showing variation of concentration of ozone with flow of air for:—

Air space (cm.) = 0.15

E.M.F. impressed (volts) = 5000

Thickness of mica (cm.) = 0.023

and plates of BRASS.



DATA FOR SPEED CURVES.

Test No. II

Plate used - Brass. Thickness of mica - .023 cm.

Voltage impressed - 5000. Air space between mica and plate - .15 cm.

Liters of air treated	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	451.0	0.13	00.00	3.00	0.0324
4.0	84.0	2.86	20.65	5.16	0.0578
4.0	80.0	3.00	18.75	4.69	0.0525
4.0	63.0	3.81	21.45	5.36	0.0600
4.0	46.5	5.17	18.05	4.51	0.0505

TEST NO. III

VOLTAGE CURVE NO. 5.

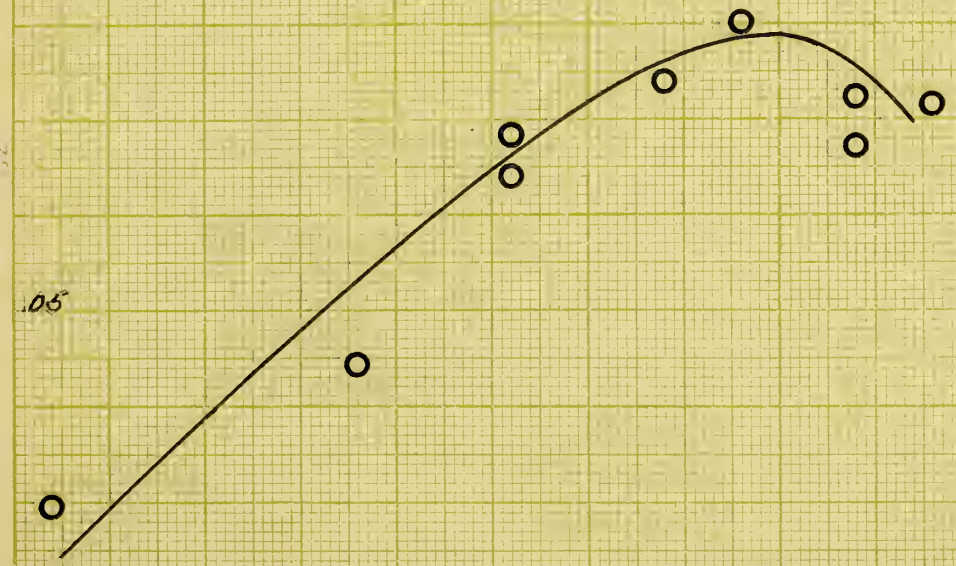
Showing variation of concentration of ozone with voltage impressed for:-

Air space (cm.) = 0.084

Air flow (liters per min.) = 3.10

Thickness of mica (cm.) = 0.025

and plates of ALUMINIUM.



DATA FOR VOLTAGE CURVES.

Test No. III

Plate used - Aluminum. Thickness of mica-.025 cm.

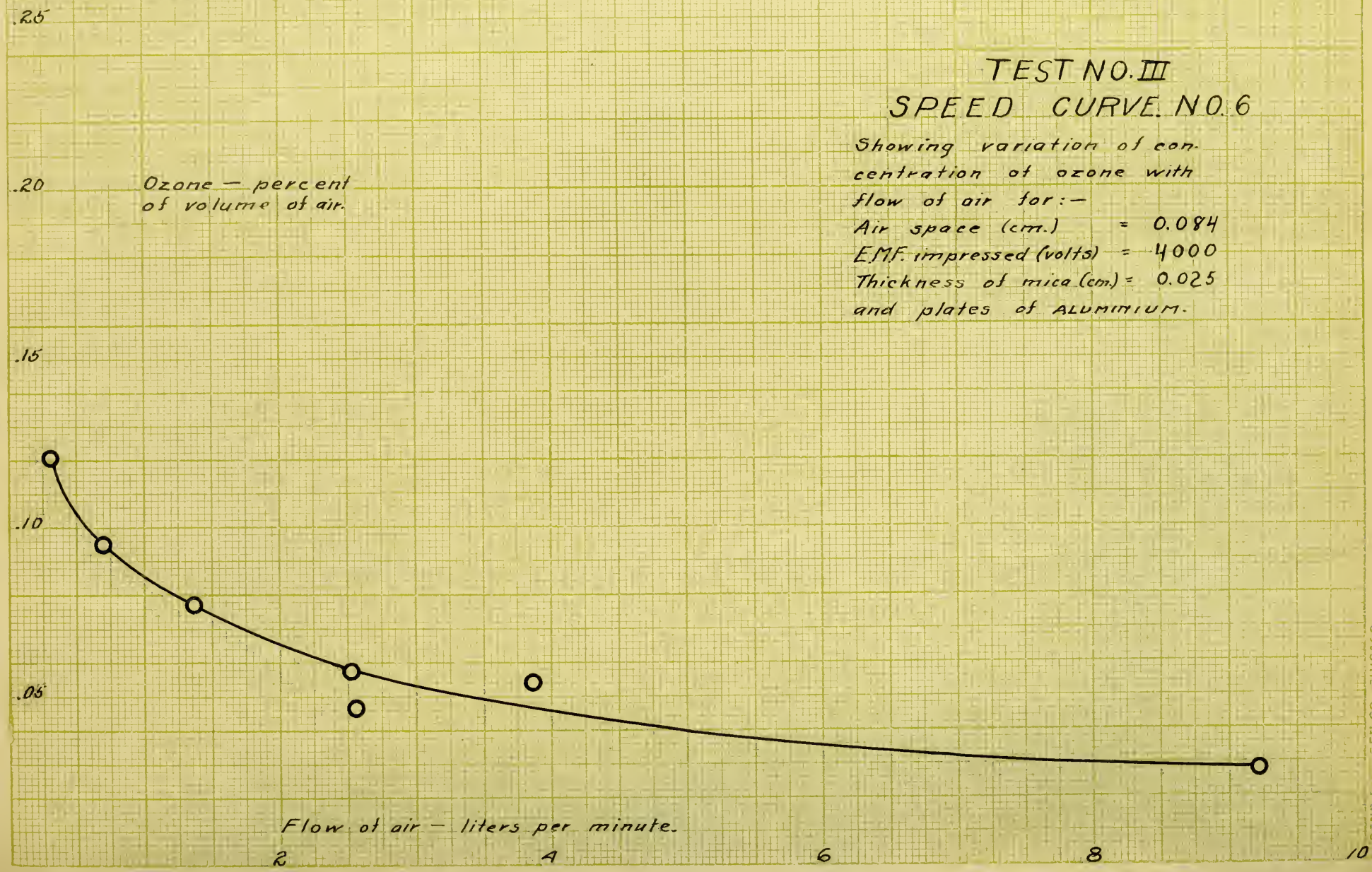
Volts impressed - 3050 - 4200. Air space between mica and plate-.084 cm.

Liters of air treated	Voltage between plates	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	3050	75.00	3.20	7.50	1.87	0.0209
4.0	3450	80.00	3.00	15.80	3.95	0.0442
4.0	3650	83.00	2.89	18.65	4.66	0.0522
4.0	3650	76.00	3.16	24.75	6.19	0.0683
4.0	3850	78.00	3.08	26.40	6.60	0.0740
4.0	3950	76.00	3.16	28.65	7.16	0.0802
4.0	4100	77.00	3.12	24.00	6.00	0.0672
4.0	4100	77.00	3.12	25.80	6.45	0.0723
*4.0	4150	90.00	2.67	15.70	3.92	0.0439
*4.0	4150	78.50	3.06	15.80	3.95	0.0438
4.0	4200	76.25	3.15	26.05	6.51	0.0719

*Electrodes heated.

TEST NO. III
SPEED CURVE. NO. 6

Showing variation of concentration of ozone with flow of air for:—
Air space (cm.) = 0.084
E.M.F. impressed (volts) = 4000
Thickness of mica (cm.) = 0.025
and plates of ALUMINIUM.



DATA FOR SPEED CURVES.

Test No. III

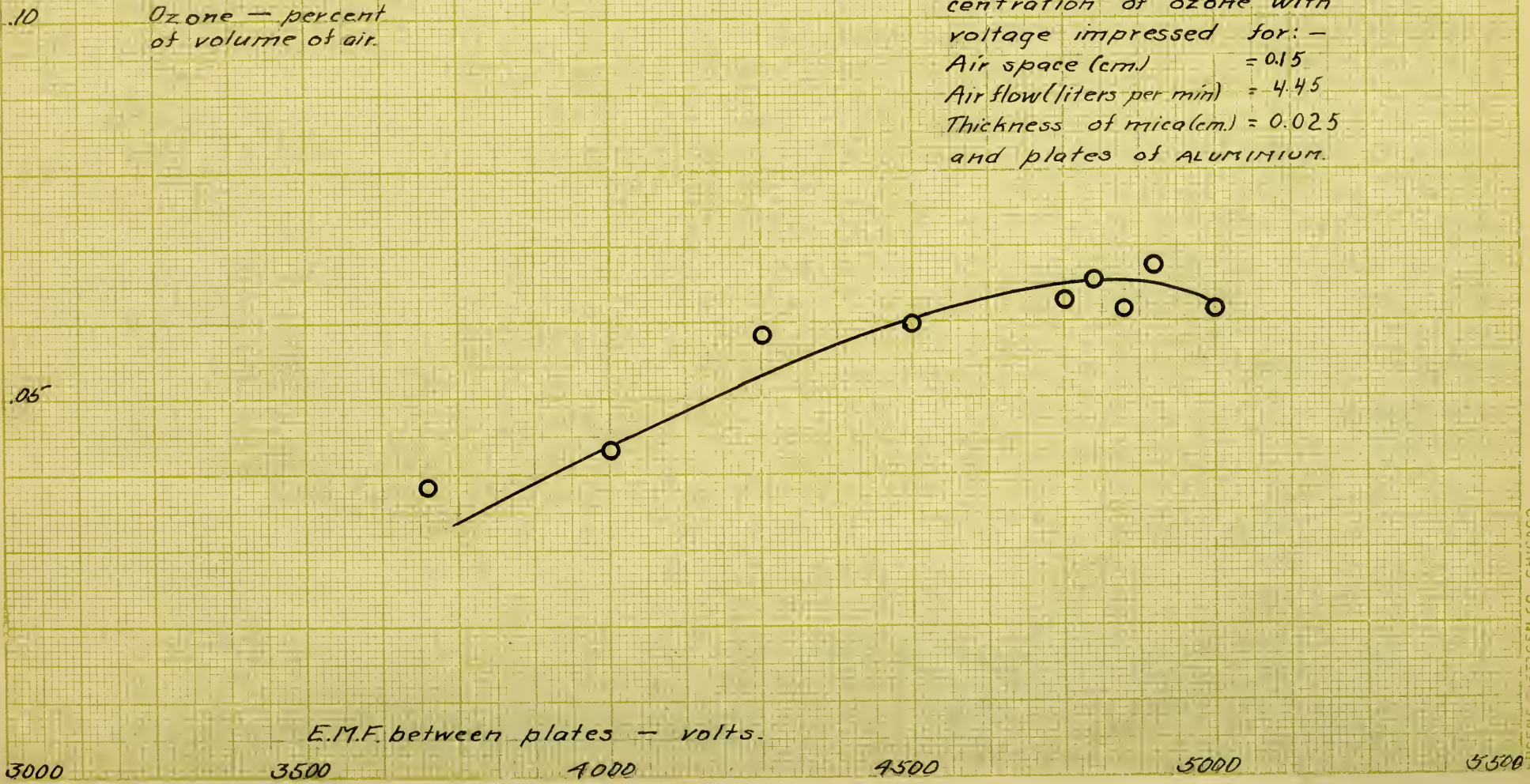
Plate used - Aluminum. Thickness of mica - .025 cm.

Volts impressed - 4000. Air space between mica and plate - .084 cm.

Liters of air treated	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	760	0.32	43.05	10.76	0.0121
4.0	344	0.70	33.90	8.47	0.0949
4.0	174	1.38	27.70	6.92	0.0775
4.0	95	2.53	20.65	5.16	0.0578
4.0	94	2.56	16.80	4.20	0.0470
4.0	62	3.87	19.35	4.84	0.0542
4.0	26	9.23	10.10	2.52	0.0283

TEST NO. IV
VOLTAGE CURVE NO. 7

Showing variation of concentration of ozone with voltage impressed for: —
Air space (cm.) = 0.15
Air flow (liters per min) = 4.45
Thickness of mica (cm.) = 0.025
and plates of ALUMINIUM.



DATA FOR VOLTAGE CURVES.

Test No. IV

Plated used - Aluminum. Thickness of mica- .025 cm.

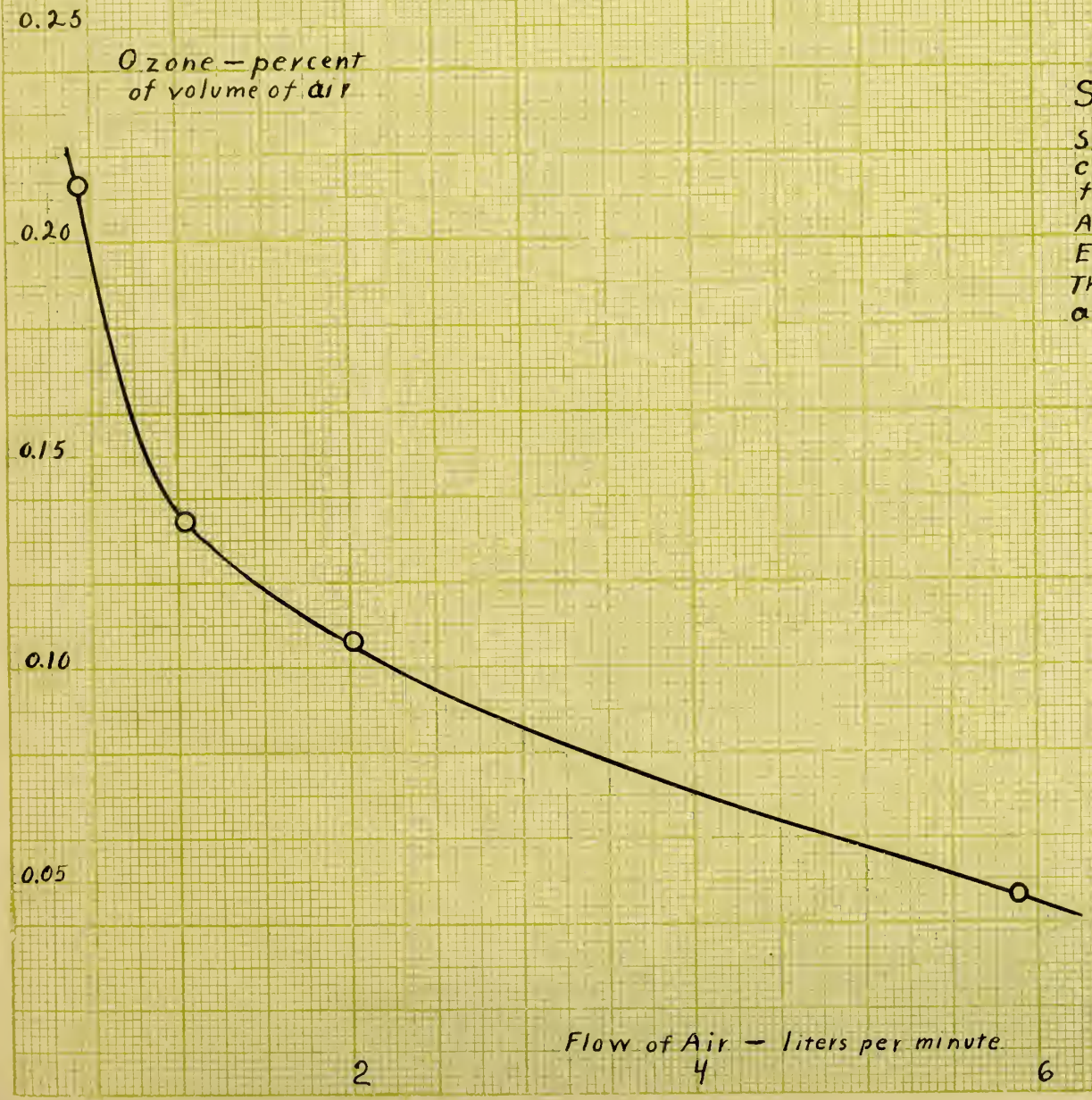
Volts impressed - 3700 - 5000. Air space between mica and plate - .15 cm.

Liters of air treated	Voltage between plates	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	3700	53.00	4.54	13.70	3.42	0.0383
*4.0	3750	50.00	4.80	10.01	2.50	0.0280
4.0	4000	54.00	4.45	19.00	4.75	0.0532
4.0	4200	55.00	4.36	20.85	5.21	0.0584
4.0	4500	51.75	4.65	21.35	5.34	0.0598
*4.0	4750	50.00	4.80	22.40	5.60	0.0627
*4.0	4800	50.50	4.75	19.65	4.91	0.0550
4.0	4800	52.00	4.62	23.45	5.86	0.0656
4.0	4850	55.25	4.35	25.85	6.46	0.0616
4.0	4900	55.00	4.36	24.10	6.02	0.0674
*4.0	5000	50.00	4.80	16.25	4.06	0.0455
4.0	5000	54.00	4.45	21.90	5.47	0.0612

* Electrodes heated.

TEST NO. IV
SPEED CURVE NO. 8.

Showing variation of Concentration of ozone with flow of air for:—
Air Space (cm) 0.15
E.M.F. Impressed (Volts) 4850
Thicknes of Mica (cm) 0.025
and plates of Aluminium.



DATA FOR SPEED CURVES.

Test No. IV.

Plate used - Aluminum. Thickness of mica - .035 cm.

Volts impressed - 4850. Air space between mica and plate - .15 cm.

Liters of air treated	Duration of treatment-sec.	Liters of air treated per min.	$Na_2S_2O_3$ required for titration-cc.	$Na_2S_2O_3$ required per liter-cc.	Percent Vol. of ozone obtained.
4.0	526.00	0.45	76.20	19.05	0.2135
4.0	239.00	1.05	48.10	12.02	0.1348
4.0	118.00	2.04	37.80	9.45	0.1060
4.0	40.75	5.90	16.65	4.16	0.0466

BACTERIOLOGICAL TESTS.

Test No. I

Sample No.	Bacteria per cc. before treatment.	Bacteria per cc. after treatment.	Percent reduction.
1	13500000	2000000	70.4
2	2000000	1810000	9.5
3	2910000	1600000	10.6
4	1810000	1600000	11.6

Test No. 2

Sample No.	Rate of flow gal. per min.	Bacteria per cc. before treatment.	Bacteria per cc. after treatment.	Percent reduction.
1	0.625	27000	16400	39.2
2	0.638	17000	11500	32.3
3	0.278	20000	8400	58.0